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ACOUSTIC MEASUREMENTS

[UNCLASSIFIED TITLE]

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CONTENTS

ABSTRACT
[Unclassified]

One objective of the Acoustic Measurements Program (NRL Problem S05-18) is to develop techniques and equipment which will permit accurate prediction, by measurement, of assured sonar range under most oceanographic conditions.

A series of measurements have been made of acoustic propagation losses. The losses are quite variable. Because of interference effects from reflected rays the predicted loss to a specific point in range and depth is subject to considerable error. Some space and time integration techniques must be used to lower these variations.

The large signal variation with depth, due to thermal structure effects, rules out the use of a single unit at one range and depth for obtaining accurate propagation loss measurements.

PROBLEM STATUS

This is an interim report on one phase of the problem; work on the problem is continuing.

AUTHORIZATION

NRL Problem S05-18
Project NE 051-60C-689C-3
BuShips No. S-1907

Manuscript submitted June 20, 1960.

ACOUSTIC MEASUREMENTS
[Unclassified Title]

BACKGROUND

An objective of the Acoustic Measurement Problem (NRL Problem S05-18) is to develop techniques and equipment which will permit accurate prediction, by measurement, of assured sonar range under most oceanographic conditions. This equipment will not only take into consideration the thermal condition but also the type and condition of sonar equipment, and the noise and reverberation background.

A series of measurements will be made (a) to develop techniques and equipment for making on the spot transmission loss measurements, (b) to investigate the feasibility of using synthetic targets for accurate range prediction, and (c) to study sound wave scattering phenomenon to relate scattering effect to the detection problem as well as range prediction. The measured results will be compared to predicted results obtained by analyzing the bathythermograph and to measured ranges using a submarine target.

One endproduct envisioned is a towed or disposable transponder unit to act as a synthetic submarine (Fig. 1). However, before the properties of such a unit can be fully outlined some analysis and field testing of propagation conditions must be done. It is the purpose of this report to present the results of some of these measurements.

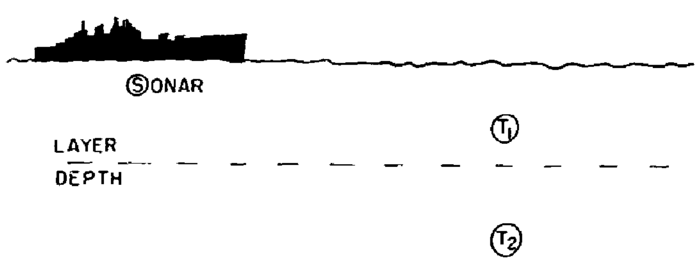


Fig. 1 - Sonar range determination: T_1 and T_2 are transponders or pulse repeaters which act as synthetic targets

ANALYSIS

If the proposed unit can use transducers having little or no directivity, then some parts of operational use are simplified. This is especially true of no directivity in the horizontal plane, since there is then no transducer training problem. One hazard in the use of omnidirectional transducers is the reflection problem. As a start, some consideration will be given to reflections and how they affect the results.

Surface Reflection

The equation which gives the locus of points of signal cancellation of the direct rays by the surface reflected rays under iso-velocity conditions is

$$D_n = \frac{nR\lambda}{2d}, \text{ if } d,\ D << R$$

where

D = receiver depth

d = projector depth

R = range

λ = wavelength

n = number of wavelengths of path length difference.

In practice, it is easier to measure the vertical spacing between nulls than to find the absolute position of each null. The null-to-null spacing is

$$\Delta D = D_n - D_{n-1} = \frac{R\lambda}{2d}.$$

Bottom Reflection

Physically, bottom reflection is similar to that of the surface, but in this case the reflection does not have a phase reversal. The null-to-null expression is

$$\Delta D = \lambda\sqrt{1 + \frac{R^2}{(B - d)^2}}, \text{ if } d,\ D << R$$

where

B = depth of water.

Reflection Off Source-Carrying Ship

The null-to-null spacing for reflection off the source-carrying ship is

$$\Delta D = \frac{R\lambda}{d - d'}, \text{ if } d,\ D << R$$

where

d' = keel depth of source-carrying ship.

Reflection Off Receiving Ship

The null-to-null spacing for reflection off the receiving ship is

$$\Delta D \approx 2\lambda, \text{ if } d,\ D << R.$$

Effect of Reflections

The null-to-null spacing will decide what type of interference is taking place. In general, the paths are not acoustically identical and the magnitude of the interference effect will depend on the relative magnitudes of the interfering signals. The equation for the resultant level of two interfering sound waves is

$$I = I_1 \pm I_2 \cos \theta$$

where

I = resultant level

I_1 = level of direct signal

I_2 = level of reflected signal

θ = relative geometrical angle of incidence.

Usually θ is small, and by defining $I_2 = aI_1$, where a is the ratio of one to the other, then

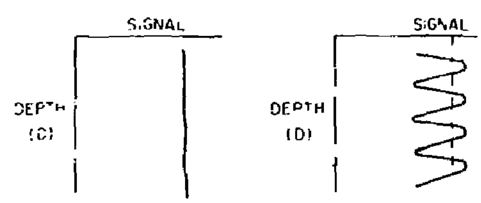
$$I = I_1 (1 \pm a).$$

When the signals add, $I = I_1 (1 + a)$, and when they subtract, $I = I_1 (1 - a)$. In the absence of an interfering signal the received signal vs depth profile is as indicated in Fig. 2a. If interference occurs this trace changes to that of Fig. 2b. Signal addition causes the trace to exceed the previous one and signal subtraction causes the trace to drop below the original one. The magnitude of the peak-to-null response is related to the relative magnitude of the two signals.

$$\text{peak-to-null} = 10 \log \frac{1 + a}{1 - a}.$$

Figure 3 is a plot of this function. (The figure includes a curve relating a in db to a expressed as a ratio.)

Fig. 2 - Signal vs depth profile; (a) without interference; (b) with interference



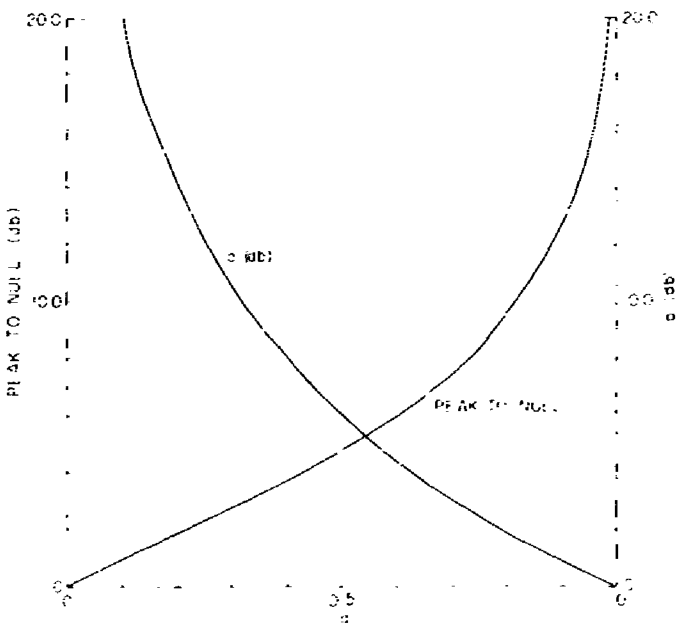


Fig. 3 – Relative signal magnitude vs interference magnitude

All of the above is based on iso-velocity conditions. This is rarely true in nature. But these results can be used as a guide or first approximation. Under conditions where there is a substantial surface layer the approximation will be good, but below the layer some error will result.

METHOD OF TAKING DATA

A signal is transmitted continuously from one ship to another while both ships are lying to. At the transmitting ship the projector is lowered to a fixed depth. The hydrophone assembly at the receiving ship is equipped with a pressure gage sensitive from 0 to 200 lb/sq in. The gage reading is converted to a depth indication. As the hydrophone is lowered the received signal and depth voltages are recorded on an X-Y recorder. Thus the resultant graph shows the signal intensity vs depth profile.

Another series of tests measures signal-to-reverberation ratios under conditions similar to above. In this case, a sonar set triggers a transponder unit having a variable source level. The reverberations are recorded on a strip chart recorder along with the transponder pulses. Signals from the transponder are varied to a level above that of the reverberations. Recordings are made at various ranges and transponder depths up to 500 feet. Of special interest is the relative change in signal-to-reverberation ratio between a transponder above the layer and one below the layer. Any change will indicate the difference in processing gain required of the sonar system to provide equivalent range coverage vs depth (see Fig. 4).

A combination of the two types of information will be used to determine the expected sonar range under both noise and reverberation limiting conditions.

RESULTS

Figure 5 shows some results under two similar conditions. The principal difference in the two cases is that the upper trace was recorded using an omnidirectional projector while in the two lower traces the projector has some directivity.

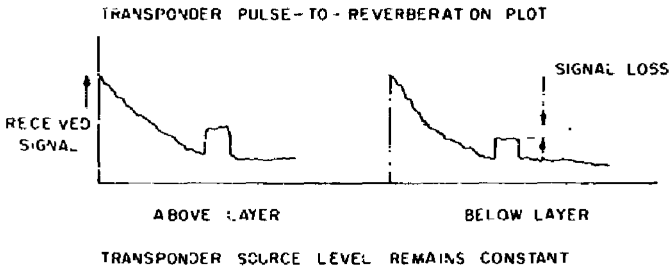


Fig. 4 - Comparison of transponder pulse at depths above and below the layer

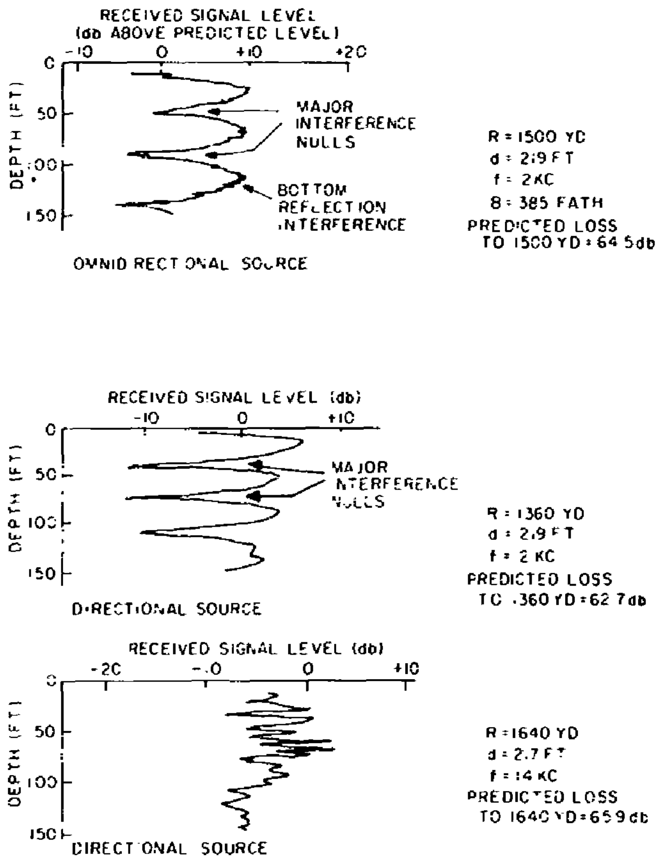


Fig. 5 - Received signal vs depth profiles (experimental)

The upper trace shows small bottom reflection effects while, in the lower traces, the use of a directive projector lowers the bottom effect to the point where it is barely seen. At the angle of transmission where sound energy reflects from the bottom to cause interference the directional transducer response is down 10 db.

The bottom-reflection peak-to-null displacement of the upper trace is about 1 db. And by using Fig. 3 the signal ratio is found to be 12 db. This figure must be corrected for the $\cos\theta$ term which was neglected in the development of Fig. 3. Under the propagation conditions used to get Fig. 5, θ is about 45 degrees. Its effect changes the signal ratio value to 15 db. Since the projector transmits omnidirectionally, the loss along the bottom-reflected path is 15 db; some of this loss occurs at the bottom and some occurs in getting to and from the bottom. Additional spreading along the reflected path accounts for 3 db; the remaining 12 db is principally reflection loss at the bottom. Amos data gives a bottom-reflection loss of 8 db.

Figures 6a and 6b are plots of the major interference null-to-null spacing against $R\sqrt{d}$. (The points indicated by x marks are those for which the recorded data is presented in the Appendix.) Judging from the slope of the curves in comparison with the theoretical curve the major interference is due to surface reflections. The displacement of the curves from the theoretical curve is probably due to not taking ray path curvature into account. When the absolute null positions, of part of the 2-kc data, are plotted, the result is as indicated in Fig. 7. Solid lines show the theoretical locus of interference minima and the dashed lines are the experimentally determined lines. The line D_1 denotes the points where the path lengths differ by $\lambda/2$, the line D_2 those that differ by $3\lambda/2$, and so on.

Figure 8 shows the received level plotted against receiver depth for several source depths. The source-to-receiver range has been kept relatively constant. Comparison is made between the measured received signal level and the predicted level. Among the propagation losses only spherical spreading and attenuation losses are accounted for in determining the calculated level. Graphs of the received level are smoothed out by drawing a line from major interference peak to major interference peak to show the envelope of the signal profile. This is justified because a submarine target is of sufficient size to cause the incident sound level to be close to that of the envelope of the interference pattern. In Fig. 8 as the source depth increases, the received level increases until the source depth is slightly greater than the layer depth. Thereafter, a source depth increase causes a decrease in the received signal. The overall received level from the 50-ft source depth is 12 db to 15 db above that from the 300-ft source depth. A greater variation (20 db) exists between the minimum value from the 50-ft source and the maximum value from the 50-ft source. Thus the use of a single transponder unit will cause considerable error in the measured loss, and the error will depend on what depth the unit is placed.

The previous measurements were made under conditions where a surface layer existed to about 90 ft, with a sharp thermocline below the layer of approximately -5°F/100 ft. When a moderate negative gradient (-1.5°F/100 ft) exists with no surface layer, the result is that of Fig. 9. There is less variation in the envelope of the received signal. In addition, there is a general increase in received level as source and receiver depths increase.

Some echo-to-reverberation measurements have been made. The results are too inconclusive to be reported.

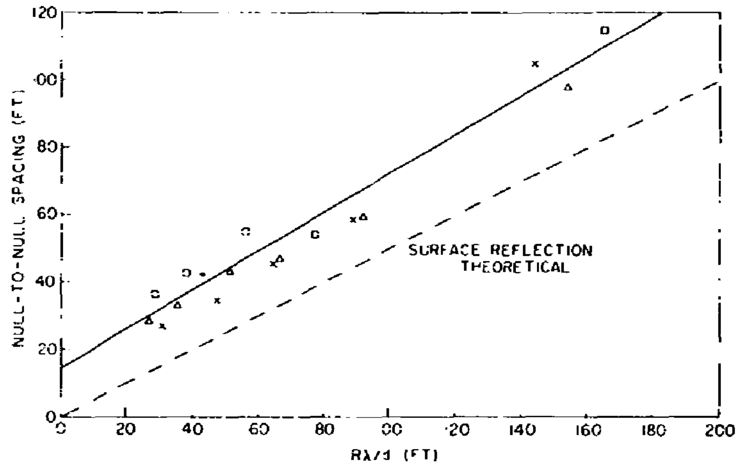


Fig. 6a - Interference spacing (2-kc source)

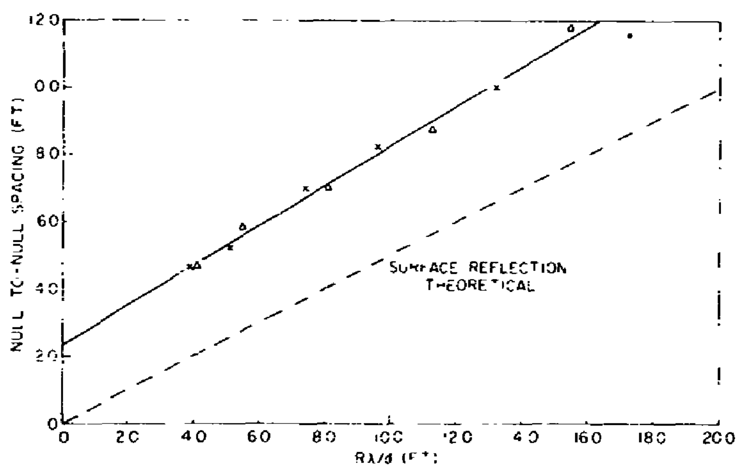
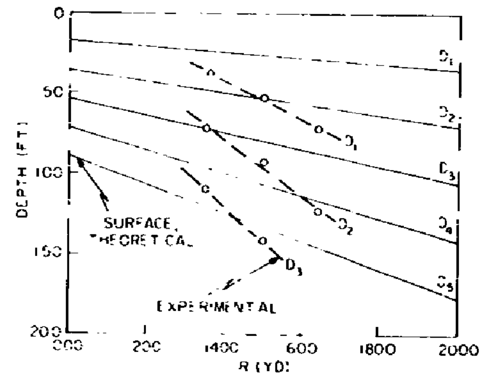
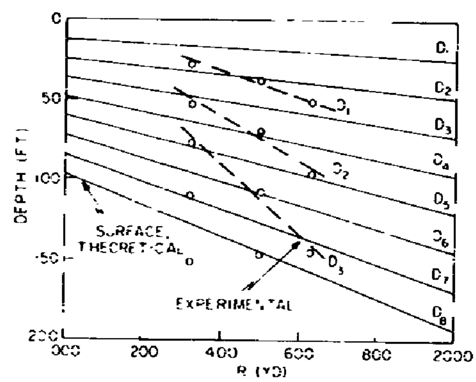


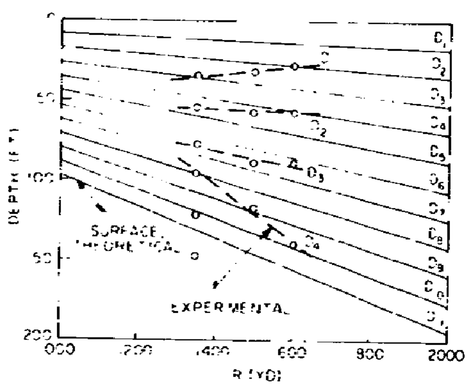
Fig. 6b - Interference spacing (14-kc source)



(a) Source depth, 219 ft

(b) Source depth, 312 ft





(c) Source depth, 407 ft

Fig. 7 – Interference locus vs range (2-kc source)

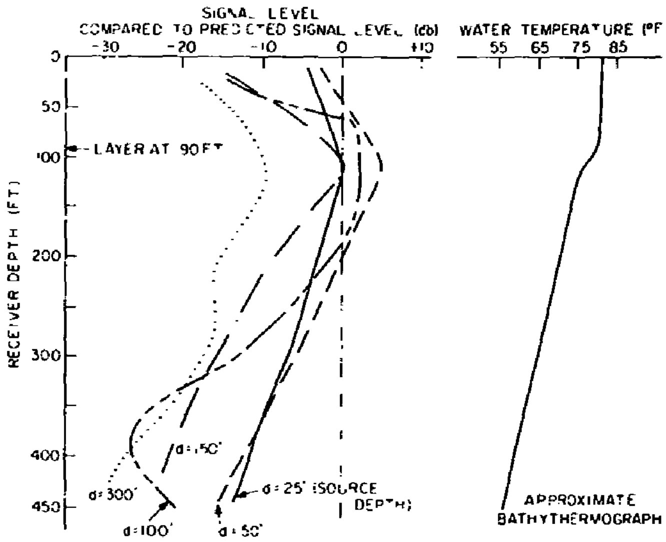


Fig. 8 – Signal profile for various source depths – under layer conditions (14 kc, R ~ 1860 yd, predicted loss to 1860 yd = 67.3 db)

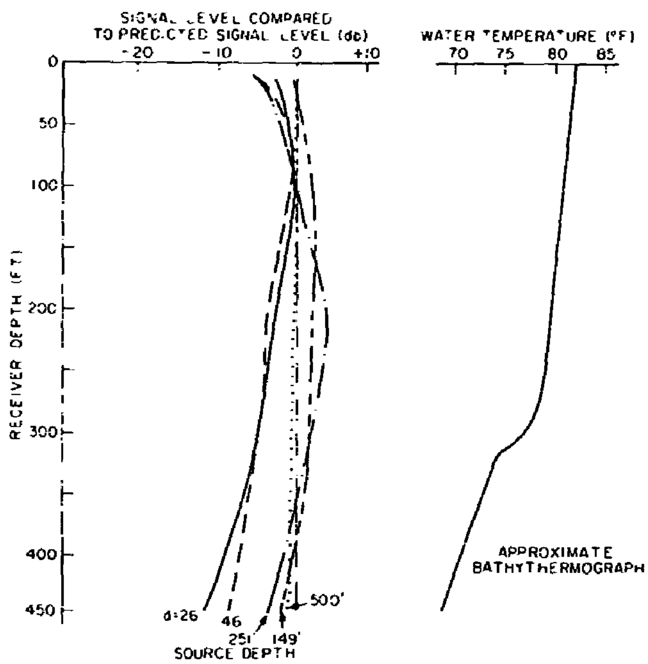


Fig. 9 – Signal profile for various source depths – under negative gradient conditions (14 kc, R ~ 2450 yd, predicted loss to 2450 yd = 70.3 db)

CONCLUSIONS

These measurements have shown the measured propagation loss to be quite variable and the loss to a specific point in range and depth to be subject to considerable error. In order to minimize these errors the sonar range measuring device must account for interference effects and thermal structure effects. In plotting the measured signals the interference effects were integrated graphically. Integration can also be done in time and in space; an increase in the receiving system time constant will integrate in time and a larger transducer will increase space integration. Space effects are dependent on $R\lambda/d$, and any change in R, λ, or d will change signal integration.

The large signal variation with depth, due to thermal structure effects, rules out the use of a single unit at one range and depth for obtaining accurate propagation loss measurements. Two units will give more information, but the error is still sizeable.

FUTURE WORK

Additional tests will be performed to measure received signal levels using the integration schemes mentioned in obtaining an envelope level free of the smaller interference effects. This level will more closely match the level incident on a submarine target.

These alterations in the measurement technique may allow the separation of propagation loss into a steady component and a variable component. Assured sonar range will be determined by the steady component.

Currently under construction is a type of transponder known as an echo repeater. Its function is to reproduce the sonar pulse, amplify it, and transmit it back to the echo-ranging ship. An amount of amplification is chosen which matches the target strength of a submarine. Other characteristics of a submarine, such as doppler, may be included later on.

More measurements should be made at 2 kc and below. This is important because of the increasing trend toward lower frequency sonars. It is also important due to the increasing problem of keeping track of propagation paths over longer ranges.

When complete sets of measurements have been performed, some echo-ranging evaluation can be done. From these sets, measurement accuracy and reliability can be compared to measurement equipment complexity.

* * *

APPENDIX A

SOME OF THE RECORDED DATA AND MODIFIED DATA ON WHICH FIGS. 6a, 6b, 8, AND 9 ARE BASED

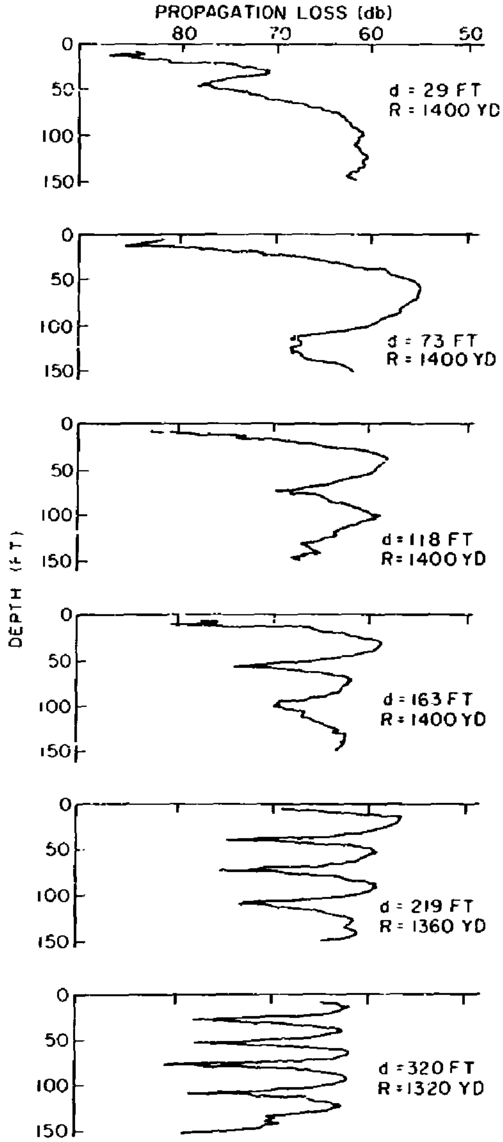
The data in Fig. A1 are used to plot Figs. 6a and 6b, where null-to-null spacing is plotted against $R\lambda/d$. Only part of the data is shown; the portion shown is indicated by x marks in Figs. 6a and 6b. For each profile the null spacing plotted is determined by dividing the number of dips in the received signal into the depth increment. The 14-kc-receiving-system time constant is 300 ms and the 2-kc one is 700 ms.

Figure A2 is the data used to get Fig. 8. Also shown is the graphic integration used to indicate the approximate profile and the approximate envelope. A good example of source-ship-reflection interference appears when $d = 25$ ft. The measured null spacing is about 150 ft, which compares favorably with the calculated, iso-velocity null spacing of 133 ft. From the magnitude of the peak-to-null displacement, which is about 12 db in this figure, the relative magnitude of the interfering signals, as determined from Fig. 3, is nearly 3 db. But the vertical response of the 14-kc projector is 20 db below the horizontal level and this tends to indicate about a 17-db target strength for the source-carrying ship.

A combination of effects occur in the 14-kc data of Fig. A1 when $d = 161$ ft. This profile is reproduced in Fig. A3 along with the envelope of the finer variations. A similar effect has occurred in other cases, one of which is included in Fig. A3. In these instances, an interference appears to exist due to the superposition of the surface and source interference. Its effect on the profile is to cause an additional interference or beat in the received signal vs depth. Under iso-velocity conditions, the depth-interval period of this beat is $R\lambda/2d'$.

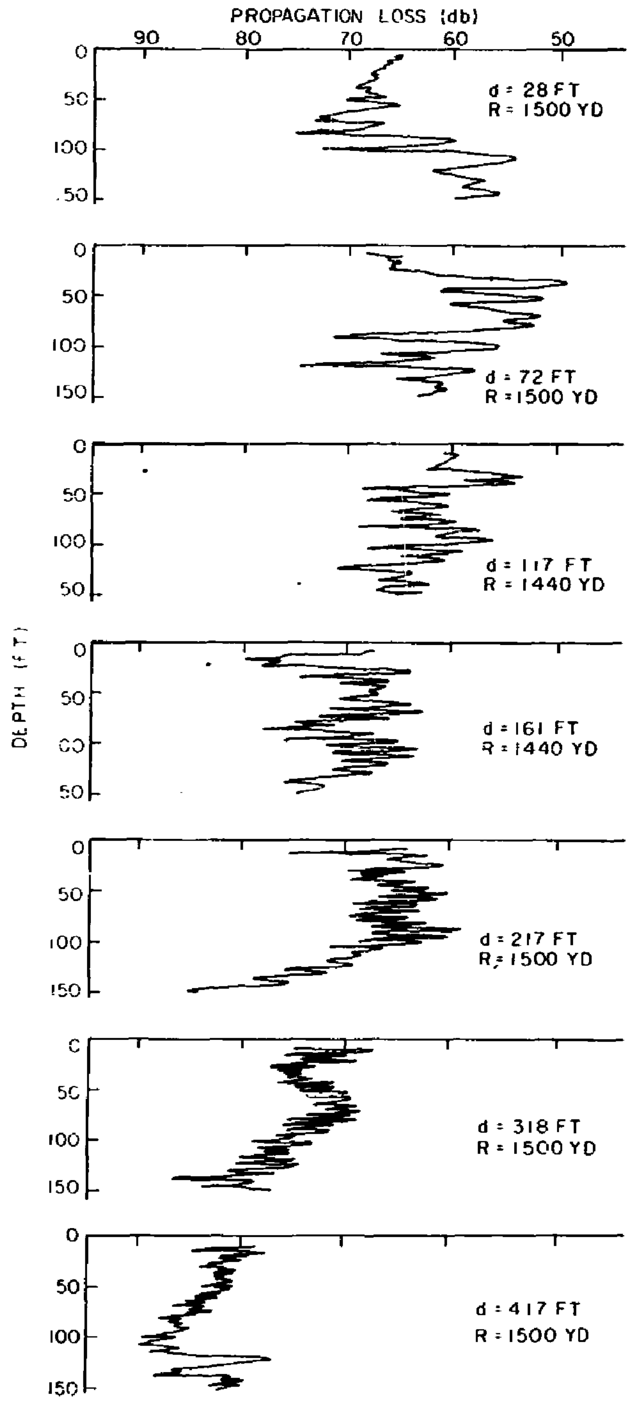
The appearance of an interference due to source-ship reflections is variable, as an examination of Fig. A2 will show. It is reasonable to assume that this reflection off the ship's hull is directional. Information on the bearing of the receiving vessel from the source vessel, and its relation to the projector was not recorded. Any detailed accounting of source interference should include this information.

Figures A4 and A5 are part of the data used to get Fig. 9. In general the null spacing of this group of measurements is not constant with respect to depth. When the null spacing of Fig. A5 is plotted against depth the result is Fig. A6. It appears that the spacing is relatively constant to about 210 ft, but thereafter the spacing increases.



(a) At 2 kc

Fig. A1 - Some of the propagation loss vs depth data used in obtaining Figs. 6a and 6b (these data are indicated by x marks in Figs. 6a and 6b)



(b) At 14 kc

Fig. A1 – Some of the propagation loss vs depth data used in obtaining Figs. 6a and 6b (these data are indicated by x marks in Figs. 6a and 6b)

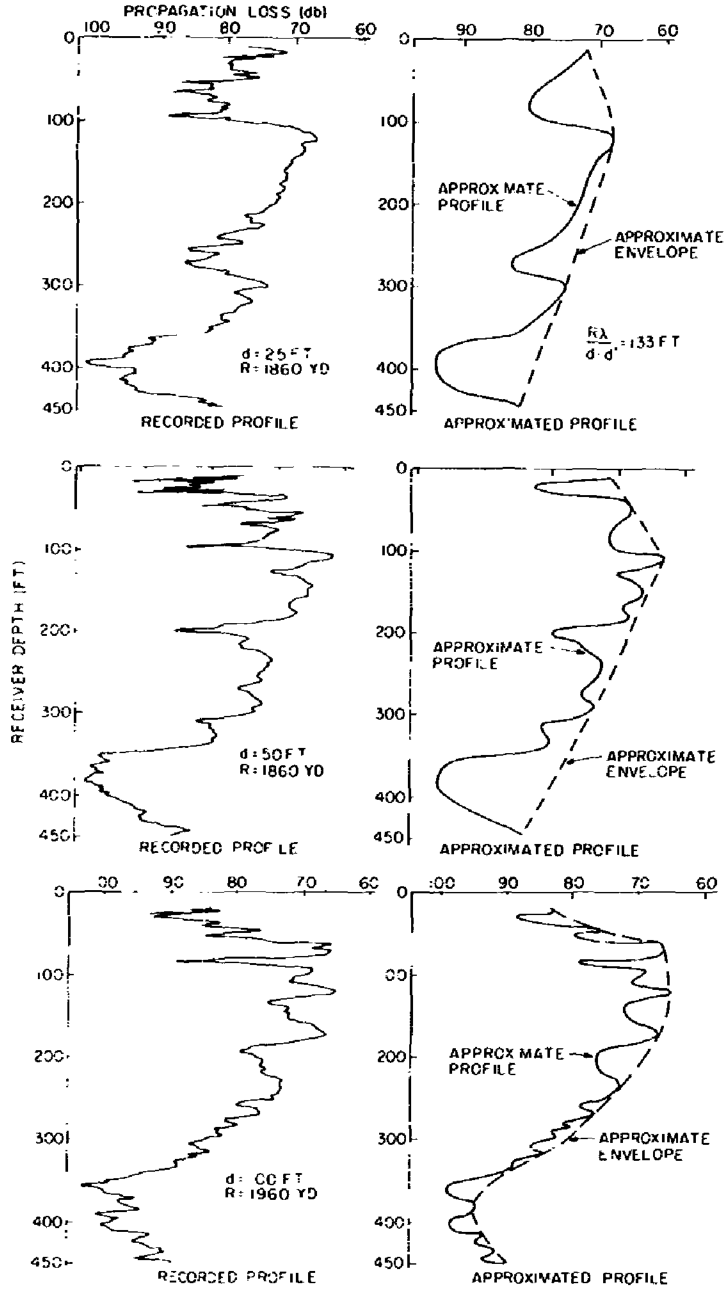


Fig. A2 - Propagation loss profiles at 14 kc, showing graphic integration method used in obtaining the curves in Fig. 8

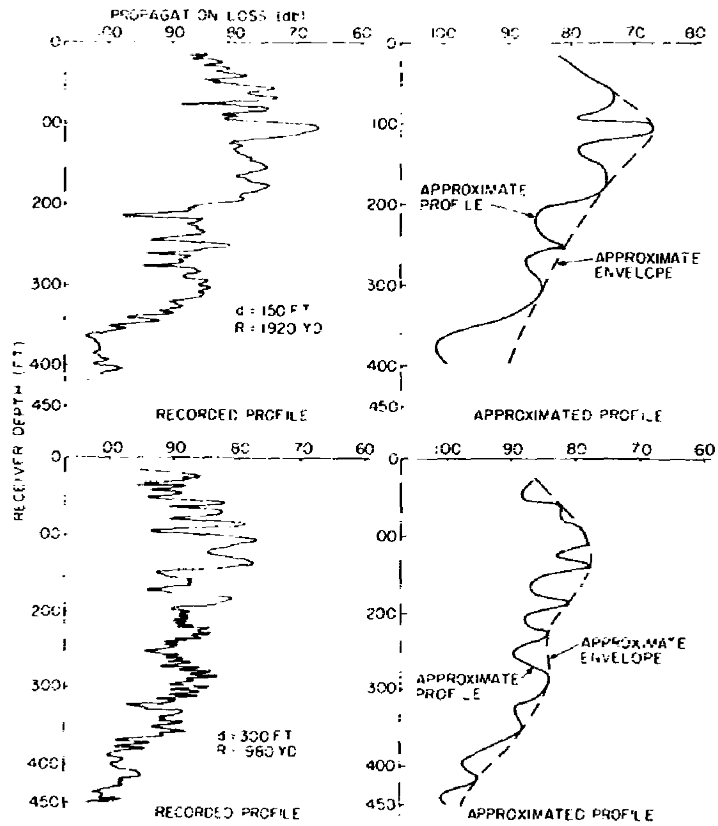


Fig. A2 - Propagation loss profiles at 14 kc, showing graphic integration method used in obtaining the curves in Fig. 8

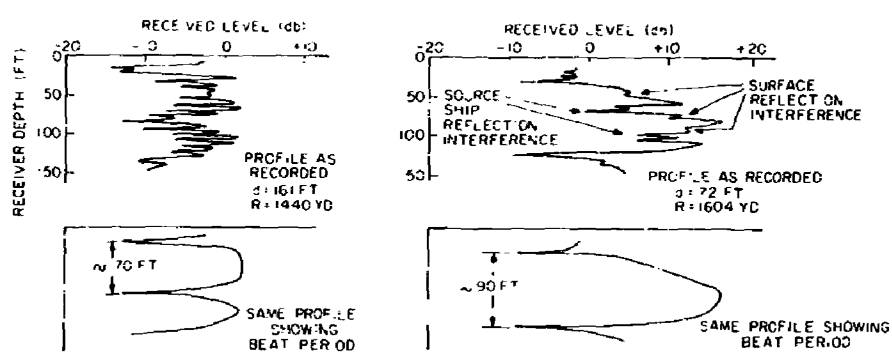


Fig. A3 - Profile showing beat of source and surface interferences

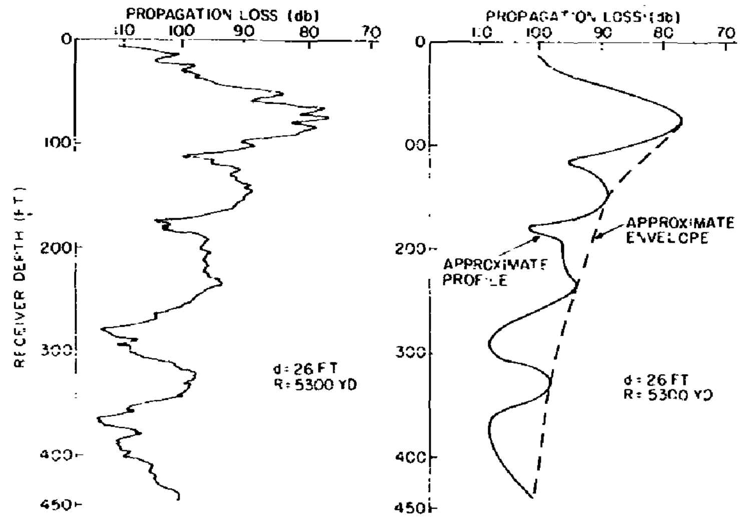


Fig. A4 – Propagation loss at 14 kc, showing the method used in obtaining the curves in Fig. 9

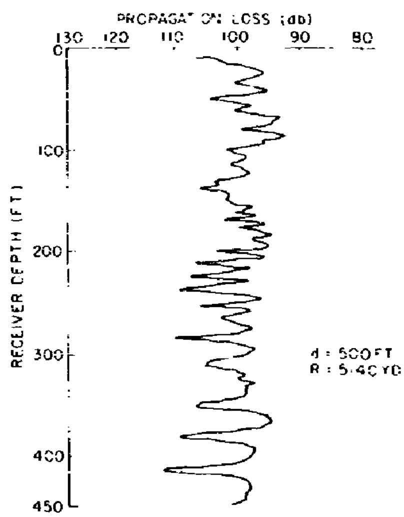


Fig. A5 – Propagation loss at 14 kc, the data for the 500-ft curve in Fig. 9

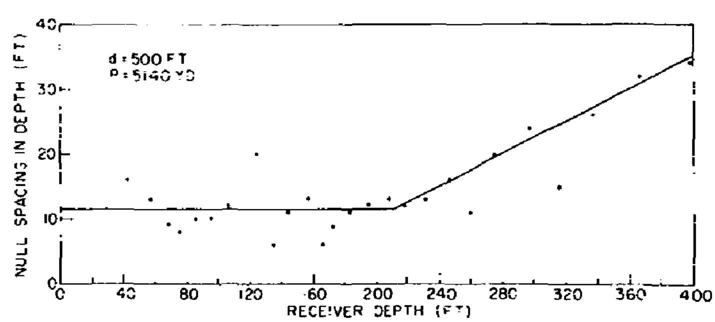


Fig. A6 – Null spacing vs depth at 14 kc as taken from Fig. A5

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memorandum

7103/138

DATE: 20 November 1996

FROM: Burton G. Hurdle (Code 7103)

SUBJECT: REVIEW OF REF. (a) FOR DECLASSIFICATION

TO: Code 1221.1

VIA: Code 7100

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REF: (a) NRL Confidential Report #5527 by J.J. Yagelowich, 28 Oct 1960 (U)

1. Reference (a) reports the comparison of a set of propagation measurements with modeling results.

2. This technology is well known today.

3. Based on the above, it is recommended that reference (a) be declassified and released with no restrictions.

Burton G. Hurdle

BURTON G. HURDLE
Acoustics Division

CONCUR:

Edward R. Franchi 11/20/96

EDWARD R. FRANCHI Date
Superintendent
Acoustics Division

Completed
1-24-2000
P.W.

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